2001

# Comparative Evaluation of Cooling Systems for Farrowing Sows

Hongmin Dong
*Chinese Academy of Agricultural Sciences*

Xiuping Tao
*Chinese Academy of Agricultural Sciences*

Yue Li
*Chinese Academy of Agricultural Sciences*

Jintian Liu
*Chinese Academy of Agricultural Machinery Sciences*

Hongwei Xin
*Iowa State University*, hxin@iastate.edu

# Comparative Evaluation of Cooling Systems for Farrowing Sows

H. Dong, X. Tao, J. Lin, Y. Li, H. Xin

**Abstract.** *The field studies reported here compare the performance of three cooling systems for relieving farrowing/lactating sows of heat stress under the warm and humid production climate in southern China. The comparative systems included (1) tunnel ventilation (TV) with vertical head–zone ventilation (HZV) vs. TV with HZV and drip cooling (DC), (2) TV only vs. TV with DC, and (3) horizontal air mixing (HAM) only vs. HAM and DC. For the HZV, a perforated overhead air duct was used to create an air velocity of 0.6 to 0.8 m/s (118 to 157 ft/min) in the head zone of the sow. The paired tests were conducted successively in an experimental commercial farrowing barn housing 42 sows. Body temperature ($T_b$) and respiration rate (RR) of the sows were used to evaluate the efficacy of the systems. The results indicate that sows under TV + DC or TV + HZV + DC had significantly lower $T_b$ than those under TV only or TV + HZV ($P < 0.01$ and $P < 0.001$, respectively). DC under HAM was less effective for $T_b$ reduction ($P > 0.05$). DC reduced RR in all cases, 42% under TV ($P < 0.01$), 41% under TV + HZV ($P < 0.01$), and 22% under HAM ($P > 0.05$). It was concluded that TV with DC provides the most cost–effective cooling scheme.*

***Keywords.*** *Drip cooling, Heat stress, Horizontal air mixing, Localized cooling, Sow, Tunnel ventilation.*

Intensive swine production in China is concentrated in the south and southwest regions that typically have hot and humid summer climates. For instance, outside air temperature averages 36.0°C (96.8°F) with a relative humidity (RH) of 75% at 1400 h during the hottest month for the city of Wuhan, Hubei Province. The 30–year extreme high dry–bulb temperature is 41.4°C (106.5°F) for the city. The adverse effects of high temperature and RH on swine productivity have caused most swine farrowing farms in southern China to temporarily suspend production during the summer months to avoid economic loss. Hence, cooling systems or methods suitable for the Chinese swine farrowing houses would have substantial economic implications.

A particularly difficult problem with farrowing house cooling is the different thermal comfort needs of the sows and the piglets. Sows are most comfortable at air temperatures of 16 to 25°C (60 to 77°F). Newborn pigs, on the other hand, require temperatures as high as 32°C (90°F) to prevent chilling. The piglets respond best to temperatures of 28 to 30°C (82 to 86°F) until weaning at 4 to 5 weeks (ASHRAE, 1997). Pigs less than 8 weeks old should not be exposed to air drafts exceeding 0.25 m/s (49 ft/min), whereas sows perform best in air velocities near 1.0 m/s (197 ft/min) in summertime (ASHRAE, 1997; Riskowski and Bundy, 1991; Xin and Deshazer, 1991; Harmon and Xin, 1996). One solution to the conflicting thermal needs is to provide separate microenvironments for sows and piglets.

Drip cooling[1] (DC) and zone ventilation for sows are among the recommended methods to maintain a comfortable house temperature for the piglets (MWPS, 1990). Head–zone ventilation (HZV) may provide an improved microenvironment for the thermal requirement of sows. According to MWPS (1990), the output rate of the nozzles for DC should range from 2 to 3 L/h (0.5 to 0.8 gal/h). For zone cooling of farrowing sows, the recommended airflow rate is 119 $m^3$/h/sow (70 cfm/sow) for uncooled air and 68 $m^3$/h/sow (40 cfm/sow) for cooled air. However, little information is available on determination of HZV rates. Information on the effect of combining HZV with DC is also limited.

The objective of this field research was to investigate a cost–effective cooling system or systems for alleviating heat stress of sows in farrowing houses under the subtropical climates of southern China. To achieve the objective, comparative evaluation of three cooling systems with regard to their efficacy on sow cooling was conducted. They were: (1) tunnel ventilation (TV) with vertical head–zone ventilation (HZV) vs. TV with HZV and drip cooling (DC), (2) TV only vs. TV with DC, and (3) horizontal air mixing (HAM) only vs. HAM with DC.

## System Design and Methods

### Experimental Swine Farrowing Facility

A commercial–scale research/demo swine farrowing house owned by the Huazhong Agricultural University (Wuhan, Hubei Province) was used for this study. The farrowing house contained 42 raised–deck crates of 1.9 × 2.0 m, distributed in two rows (Figure 1). The house was

Article was submitted for review in June 1999; reviewed and approved for publication by the Structures & Environment Division of ASAE in September 2000. Presented at the 1998 ASAE Annual Meeting as Paper No. 98–4073.

The authors are **Hongmin Dong, *ASAE Member Engineer,*** Professor, **Xiuping Tao,** Assistant Professor, and **Yue Li,** Associate Professor, Agrometeorology Institute, Chinese Academy of Agricultural Sciences; **Jintian Lin**, Senior Engineer, Chinese Academy of Agricultural Machinery Sciences, Beijing, China; and **Hongwei Xin, *ASAE Member Engineer,*** Associate Professor, Agricultural Engineering Dept., Iowa State University, Ames, Iowa. **Corresponding author:** Dr. Hongmin Dong, Agrometeorology Institute, Chinese Academy of Agricultural Sciences, 30 Baishiqiao Road, Beijing 100081, P.R. China; phone: 86–10–68919979; fax: 86–10–68975409; e–mail: donghm@mail.caas.net.cn.

1 Abbreviations: DC = drip cooling, HAM = horizontal air mixing, HZV = head–zone ventilation, RH = relative humidity, RR = respiration rate, TV = tunnel ventilation.

  

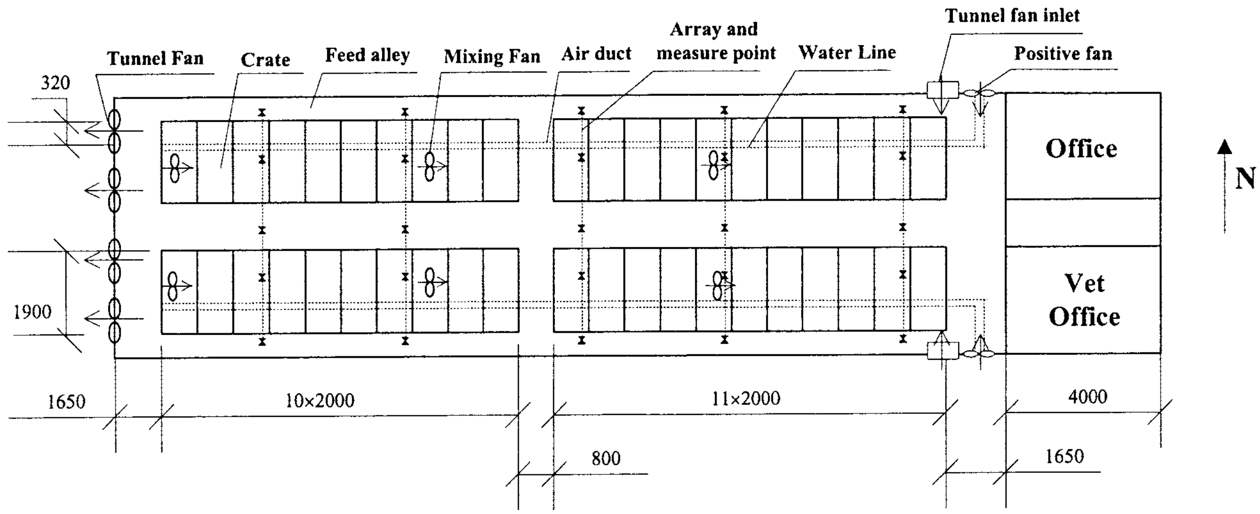


**Figure 1. Plan view of two–row, raised–deck farrowing house equipped with three types of ventilation systems (unit: mm). The dash lines stand for drip cooler lines. Symbols "x" indicate measurement arrays and points. (Not drawn to scale.)**

8.0 m wide × 46 m long, and had an eave height of 3.5 m and an east–to–west orientation. Glass windows (each 1.8 m wide × 1.6 m high) were along both south and north sidewalls and spaced 1.5 m apart. Commercial feeders and nipple drinkers were used. Prior to this project, the house had used conventional mixing fan ventilation involving six horizontal mixing fans 0.61 m in diameter (1.8 kW or 2.4 HP per fan; 13 020 $m^3$/h or 7664 cfm airflow rate per fan). The mixing fans were arranged in two rows and aligned 1.2 m above the center of the crates. The three fans in each row were located 14, 29, and 43 m, respectively, from the east end of the house.

To evaluate the effectiveness of alternative cooling systems, the farrowing house was remodeled in 1997 to incorporate a DC system and two experimental ventilation systems of TV and HZV.

**The Tunnel Ventilation (TV) System.** The TV system was expected to enhance the building ventilation and thus temperature control. Four tunnel fans (two large and two small fans) were installed at the west end of the house, 0.30 m above the crate floor level. Each large fan was 1.35 m in diameter, with a 0.75 kW (1 HP) motor and 32 000 $m^3$/h (18 835 cfm) capacity at static pressure of 39.2 Pa (0.16 in. $H_2O$), and each small fan was 0.6 m in diameter, with a 0.25 kW (0.34 HP) motor and 8250 $m^3$/h (4856 cfm) capacity at static pressure of 39.2 Pa (0.16 in. $H_2O$). The last set of windows at the east end of the farrowing house served as the air inlets for the TV operation (Figure 1).

**Positive Pressure Head–Zone Ventilation (HZV) System.** The HZV system was designed and installed to provide cool air at high velocities to the head area of the sows (Figures 1, 2). Two supply fans were installed 2.6 m above the crate level in the east–end sidewalls, one for each row of crates. A 90° galvanized elbow (1.6 m × 1.4 m) was used to connect each supply fan to its plastic distribution duct. The lowest point of the plastic distribution duct was 1.2 m above the crate floor level. The HZV system used only the distribution ducts and no downspouts. Fresh air was introduced to the sows via vent holes at the bottom of the ducts, one vent hole per crate.

*Determination of HZV Rate.* The purposes of HZV are to provide an air stream at 0.6~1.0 m/s (118 to 197 ft/min) (ASHRAE, 1997) and fresh air at 120 $m^3$/h/sow (71 cfm/sow) (MWPS, 1990) to accelerate the evaporation of the sow's respiration heat. Hence, the total ventilation rate per duct (Q) was determined as Q = 120 $m^3$/h × 21 = 2520 $m^3$/h (1483 cfm). A plastic supply duct with a 0.46 m diameter was used for the HZV system based on the recommended air velocity of 4~6 m/s (787~1181 ft/min) for pressure ventilation ducts. The vent holes of 4.5 cm diameter were used to achieve the target air velocity near the head area of the sow without creating drafts in the creep area.

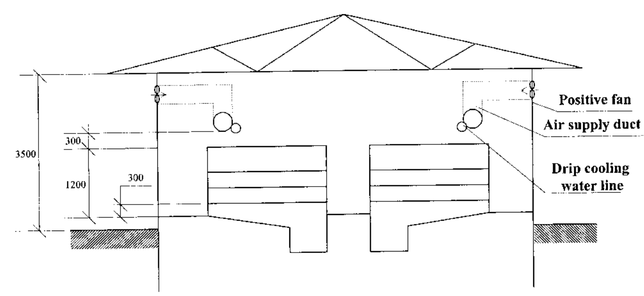


**Figure 2. Cross–sectional view of the experimental farrowing house with the head–zone ventilation system. The raised crate decks were arranged in two rows. (Not drawn to scale. Unit: mm.)**

*Determination of Supply Fan Pressure.* The supply fan must have enough air delivery capacity at the static pressure required to push air through the distribution duct. Based on duct design principle, the relationship for the airflow resistance between two sections can be expressed as follows (Lu, 1987):

$$P_{j1} + V_{d1}^2 \times \varrho/2 = P_{jn} + V_{dn}^2\varrho/2 + \Sigma\,(P_m L_n + \Delta P_{zn}) \quad (1)$$

$$P_{jn} = P_{j1} + \varrho/2(V_{d1}^2 - V_{dn}^2) - \Sigma\,(P_m L_n + \Delta P_{zn}) \quad (2)$$

where:

$P_{j1}, P_{jn}$ = static pressure at section 1–1 and section n – n (Pa)

$L_n$ = distance between section n–n and section n + 1 – n + 1 (m)

$V_{d1}$, $V_{dn}$ = average air velocity in the duct at section 1 – 1 and section n – n (m/s)

$P_m$ = pressure loss due to friction loss per unit length (Pa/m). It was calculated from empirical equations (Lu, 1987) for plastic duct. When diameter of the section n – n ($D_n$) = 0.2 ~ 2.0 m (0.7 ~ 6.6 ft) and $V_{dn}$ =3 ~ 20 m/s (590.6 ~ 3937.2 ft/min), then

$$P_m = 1.13 \times 10^{-2} \times D_n^{-1.19} V_{dn}^{1.833} \quad (3)$$

$\Sigma\Delta P_{zn}$ = sum of duct dynamic pressure loss (Pa)

$\Delta P_{zn}$ = dynamic pressure loss between sections n and n+1

$$\Delta P_{zn} = \zeta n V_{dn}^2 \varrho/2 = \zeta_v P_{dn} \quad (4)$$

$P_{dn}$ = The velocity pressure at section n

$$\zeta_v = 0.35 \times (Q_0/Q_n) \quad (5)$$

$Q_0$ = airflow rate per hole ($m^3$/s)

$Q_n$ = air flow rate of the duct before the hole ($m^3$/s)

Based on the above equations, the necessary static pressure and total pressure of the fan were 70 and 81 Pa, respectively. According to the ventilation rate and the fan pressure calculated above, two industrial fans of 45 cm diameter, 1.25 kW (1.7 HP), 3300 $m^3$/h (1942 cfm) capacity at pressure 232 Pa (1 in. $H_2O$) were selected.

**Drip Cooling (DC) System.** DC nozzles (made in China) were installed at 1.2 m above the crate floor and 0.3 m behind the headgate of the stall so that the water droplets fell onto the shoulder area of the sow without wetting the feed. The output rate of the nozzle was approximately 2 L/h (0.5 gal/h) (Figures 1, 2).

### Experimental Design and Measurements

The study involved three ventilation systems: HAM, TV, and HZV. To evaluate the cooling efficacy of combining each ventilation style with DC, the following comparisons were formed: (1) TV with HZV vs. TV with HZV and DC, (2) TV only vs. TV with DC, and (3) HAM only vs. HAM with DC. One comparison was performed at a time, with the two regimens assigned to the respective crate rows. Body temperature ($T_b$) and respiration rate (RR) of the sows were measured from 12 randomly selected sows, six sows per regimen per row. Rectal thermometer at an accuracy of 0.1°C was used for the $T_b$ measurement and manual counting of the flank movement of the sow was used for the RR measurement. The evaluations were conducted during the summer of 1997 and 1998.

The effects of adding HZV and DC to TV system on sows were evaluated during summer 1997. In addition to the TV applied to the entire building, sows in one crate row received HZV and sows in the other row received HZV and DC. Thus the experimental regimens were TV + HZV and TV + HZV + DC. During the testing period, TV and HZV were running continuously. DC was activated for 15 min every 30 min when the house temperature exceeded 30°C. Body temperature ($T_b$) and respiration rate (RR) of six sows in each regiment were measured before activation of DC and 10 min following a DC session.

The evaluation continued in summer 1998, with the objectives to determine the air temperature threshold to activate the cooling system and the cost effectiveness of each system. The comparisons had the following scheme: (1) TV with HZV vs. TV with HZV and DC (13–16 July), (2) TV only vs. TV with DC (17–19 July), and (3) HAM only vs. HAM with DC (20, 25–27 July). For each comparison, $T_b$ and RR of 12 sows, six per regimen, were measured after 20 min of DC, and performed 5 times a day at 0730, 1030, 1200, 1400, and 1600 h, respectively. The later four measured values were used to compare with the 0730 h value. The potential effects of crate location on the sow responses were checked with all the sows subjected to the same ventilation style and no DC. The result proved negative.

Variables reflecting the performance of the ventilation systems were also measured. Specifically, for the HZV system, air velocity at the pig level, 0.9 m and 1.2 m (i.e., outlets of the supply air duct) above the crate floor level was measured using a hot wire anemometer (±2% accuracy). Each level contained three measurement points located at the left–half center, center, and right–half center of the air jet, and the average value was used. The longitudinal distribution of air velocity for the TV and HAM systems was measured with five cross–sectional arrays (1 to 5) located at 4, 14, 22, 30.8, and 38.8 m, respectively, from the east end of the farrowing house. Each array contained 5 air speed measurement points (1 to 5) at 0.8, 2.4, 3.5, 5.6 and 7.2 m, respectively, from the south sidewall, all being 0.3 m above the crate floor level (Figure 1). All air velocity readings were taken twice during a 3–day experimental period. Electricity consumption of each system was calculated based on the motor power rating and runtime.

Inside air temperature and RH were measured at the same five cross–sectional arrays that were used for air velocity measurement. Each array had three temperature and RH measurement points (south, center, and north) at the pig level. Thermocouples were used for the air temperature measurement and a sling psychrometer (±0.1°C accuracy) for measurement of dry–bulb and wet–bulb temperatures and thus RH. The outside temperature and RH were recorded using the sling psychrometer. All instruments had been calibrated prior to the experiment. The measurement readings were taken at 2–h intervals.

Two–tailed t–tests were performed to evaluate the treatment effects.

## Results and Discussion

### Air Distribution of the Experimental Ventilation Systems

Longitudinal air distribution of the HZV system is shown in Figure 3. Air velocity was 10.0 ± 0.42 m/s (1969 ± 83 ft/min) at the outlets, averaged 3.0 ± 0.36 m/s (591 ± 71 ft/min) at the horizontal plane 0.9 m above the crate floor, and 0.7 ± 0.10 m/s (138 ± 20 ft/min) at the horizontal plane of pig level. Comparison of the predicted air velocities with the measured values revealed a difference of 22% for the pig

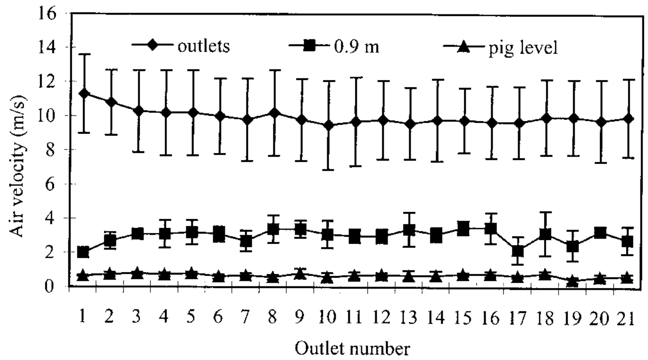


**Figure 3. Air velocity of the experimental positive head–zone ventilation at different height and outlets (mean ± SD) (1 m/s = 197 ft/min).**

level (0.9 vs. 0.7 m/s), 3% for 0.9 m horizontal plane (2.9 vs. 3.0 m/s), and 1% at the outlets (9.9 vs. 10.0 m/s). The larger difference for the sow level could have been attributed to the resistance to the jet flow by the sows.

Figure 4 shows the air velocity distribution of the TV system with four tunnel fans running. The average air velocity was 0.51 m/s (100 ft/min). Although this value was considerably lower than the desired level of 1.0 ~ 1.5 m/s (197 ~ 295 ft/min) for cooling the sow, the less draft should be beneficial for the well–being of the piglets. The TV system had a total electric energy use of 2.0 kWh.

Air velocity distribution of the HAM system is shown in Figure 5. The average air velocity was 0.4 m/s (79 ft/min). Total electric energy use of the HAM system was 10.8 kWh, 5.4 times the energy use by the TV system.

From the results it can be noted that the air jet of the HZV system had a higher velocity around the sow area than that of the HAM or TV system. The HAM system had the lowest air velocity, most unevenly distributed air, and the highest energy use. Thus in summer when HZV and DC systems are used, TV can be used to supplement air exchange to better control temperature inside the building.

### Air Temperature and Physiological Responses ($T_b$ and RR) of the Sow

**Comparison of TV with HZV vs. TV with HZV and DC During Summer 1997.** Body temperature ($T_b$) of the sows and air temperature inside the building during the period of 13–15 August 1997 are shown in Table 1. The average $T_b$ of sows subjected to TV + HZV +DC was 0.5°C (0.9°F) lower than that of sows subjected to TV + HZV. Although no statistical significance was detected for this $T_b$ reduction, the magnitude is appreciable from the standpoint of helping the sows to maintain homoeostasis.

**Comparisons of Three Cooling Systems During 1998.** Because of the positive results of the 1997 test with applying DC to TV + HZV, tests were continued in 1998 to identify a cost–effective cooling system among three systems: (1) TV with HZV vs. TV with HZV and DC, (2) TV only vs. TV with DC, and (3) HAM alone vs. HAM with DC. Measurements were conducted for 11 summer days in 1998. Because the high outside $T_a$ started earlier in the day than it did in the previous year, cooling was started at 0900 h and continued till 1600 h. The average $T_b$ and RR of the sows during this period are shown in Table 2. TV or TV + HZV coupled with DC cooled the sows reasonably well. Inclusion of DC in the

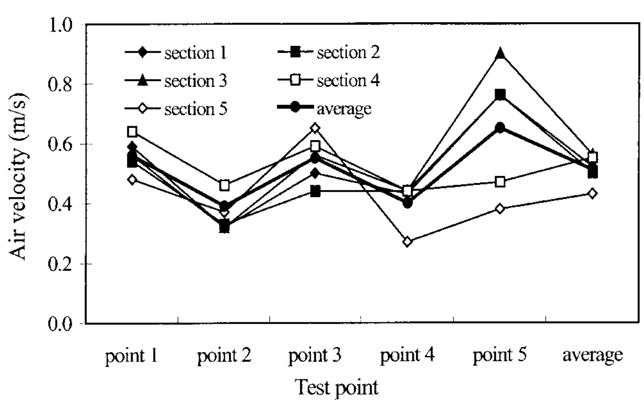


**Figure 4. Cross–sectional air velocity distribution of the tunnel ventilation system with four fans in operation (1 m/s = 197 ft/min). Sections 1–5 were located 4, 14, 22, 30.8, and 38.8 m, respectively, from the east end of the house. For each section, measurement points 1–5 were 0.8, 2.4, 3.5, 5.6, and 7.2 m, respectively, from the south sidewall.**

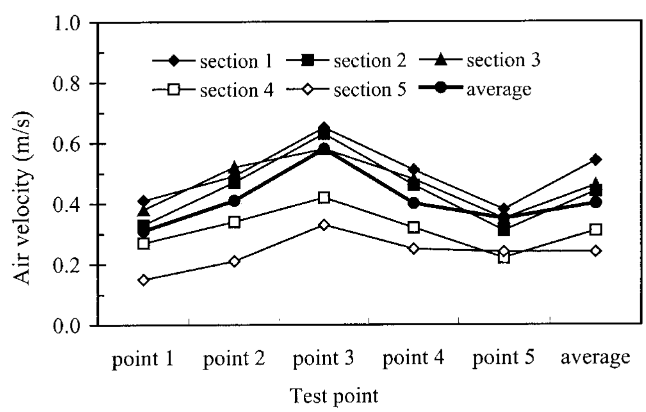


**Figure 5. Air velocity distribution of the horizontal air mixing ventilation system (1 m/s = 197 ft/min). Sections 1–5 were located 4, 14, 22, 30.8, and 38.8 m, respectively, from the east end of the house. For each section, measurement points 1–5 were 0.8, 2.4, 3.5, 5.6, and 7.2 m, respectively, from the south sidewall.**

**Table 1. Average inside air temperature ($T_a$) above 30° C and body temperature of lactating sows ($T_b$) under tunnel ventilation (TV) with head–zone ventilation (HZV) and drip cooling (DC), and TV with HZV.**

| | | 13 Aug 1997 | 14 Aug 1997 | 15 Aug 1997 | Overall |
|---|---|---|---|---|---|
| Average $T_a$ above 30°C (86°F) (mean ± SD) | °C | 32.7 ± 0.4 | 32.5 ± 0.3 | 32.2 ± 0.4 | 32.5 ± 0.3 |
| | °F | 90.9 ± 0.7 | 90.5 ± 0.5 | 90.0 ± 0.7 | 90.5 ± 0.5 |
| Average $T_b$ under TV+HZV+DC (mean ± SD) | °C | 39.5 ± 0.5 | 39.5 ± 0.3 | 39.5 ± 0.6 | 39.5 ± 0.5 |
| | °F | 103.1 ± 0.9 | 103.1 ± 0.5 | 103.1 ± 1.1 | 103.1 ± 0.9 |
| Average $T_b$ under TV+HZV (mean ± SD) | °C | 40.0 ± 0.3 | 40.0 ± 0.2 | 39.9 ± 0.4 | 40.0 ± 0.3 |
| | °F | 104.0 ± 0.5 | 103.8 ± 0.4 | 104.0 ± 0.7 | 104.0 ± 0.5 |

There were no significant differences among the means (P > 0.05).

Table 2. **Body temperature ($T_b$) and respiration rate (RR) of lactating sows under different cooling systems (mean ± SD), measured during the period of 13 July 1998 to 27 July 1998.**

| Test | $T_b$, °C (°F) | | RR, breath/min | | $T_b$ Reduction, °C (°F) | RR Reduction, breath/min (%) | Inside $T_a$, °C (°F) | Inside RH, (%) | Outside $T_a$, °C (°F) |
|---|---|---|---|---|---|---|---|---|---|
| | Ctrl | Trt | Ctrl | Trt | | | | | |
| I | 39.9 ± 0.2[a] (103.8 ± 0.4) | 39.1 ± 0.1[b] (102.4 ± 0.2) | 86 ± 15[x] | 51 ± 9[y] | 0.8 (1.4) | 35 (41%) | 33.1 ± 1.0 (91.6 ± 1.8) | 74 ± 5 | 35.9 ± 0.7 (96.6 ± 1.3) |
| II | 39.5 ± 0.2[x] (103.1 ± 0.4) | 39.0 ± 0.2[y] (102.2 ± 0.4) | 79 ± 8[x] | 46 ± 10[y] | 0.5 (0.9) | 33 (42%) | 31.5 ± 0.9 (88.7 ± 1.6) | 83 ± 3 | 32.8 ± 1.4 (91.0 ± 2.5) |
| III | 39.2 ± 0.2 (102.6 ± 0.4) | 39.2 ± 0.2 (102.6 ± 0.4) | 69 ± 9 | 54 ± 17 | 0.0 (0.0) | 15 (22%) | 33.3 ± 1.7 (91.9 ± 3.1) | 77 ± 6 | 34.2 ± 2.3 (93.6 ± 4.1) |

a, b Significantly different at $P < 0.001$
x, y Significantly different at $P < 0.01$
$T_a$ = air temperature

I (13–16 July 1998) Ctrl: tunnel ventilation (TV) with head–zone ventilation (HZV)
Trt: TV with HZV and drip cooling (DC)
II (17–19 July 1998) Ctrl: TV only
Trt: TV with drip cooling (DC)
III (20, 25–27 July) Ctrl: horizontal air mixing (HAM) only
Trt: HAM with DC

TV and TV + HZV systems reduced $T_b$ by 0.5°C and 0.8°C, respectively, and reduced RR by 42% and 41%, respectively, compared to the absence of DC. These results further confirmed the merit of DC. Considering the cost effectiveness of the system operation, TV with DC was the best choice.

### Estimation of Temperature Threshold for DC Operation

To determine the air temperature threshold to activate DC, $T_b$ of sows under TV with or without DC on the warm summer days were examined (Table 3). When inside air temperature reached 29.3°C with a coincident RH of 89%, $T_b$ of sows without DC started rising; whereas, $T_b$ of sows with DC remained unaffected. Therefore it was concluded that when the inside air temperature reaches 29°C with a RH of 89%, DC should be activated. However, limited combinations of air temperature and RH did not allow determination of the ambient temperature thresholds for different RH levels.

## Conclusions

Three cooling systems for relieving farrowing/lactating sows of heat stress were compared using a commercial–scale farrowing building in southern China. The comparisons included: (1) tunnel ventilation (TV) with vertical head–zone ventilation (HZV) vs. TV with HZV and drip cooling (DC), (2) TV only vs. TV with DC, and (3) horizontal air mixing (HAM) only vs. HAM with DC. Body temperature ($T_b$) and respiration rate (RR) of the sows and energy use were used as the evaluation criteria of the system efficacy. The following conclusions were drawn from this field study:

- Use of DC with TV or TV + HZV reduced $T_b$ of the sow by 0.5 ~ 0.8°C as compared with absence of DC ($P < 0.01$).
- DC under HAM system was less effective on $T_b$ reduction ($P > 0.05$).
- DC reduced RR in all cases, 42% ($P < 0.01$) under TV, 41% ($P < 0.01$) under TV + HZV, and 22% ($P > 0.05$) under HAM as compared with its absence.
- HAM was most energy intensive. TV + DC provides the most cost–effective cooling scheme.
- Cooling should be initiated when house temperature reaches 29°C with a RH of 89%.


### Acknowledgements

Funding for this study was provided by the Chinese Ministry of Agriculture and is acknowledged with gratitude. The assistance and cooperation provided by Huazhong Agricultural University during the course of the experiment is also appreciated.


Table 3. **Air temperature ($T_a$) and average body temperature ($T_b$) of 12 lactating sows (six in each group) subjected to tunnel ventilation (TV) with or without drip cooling (DC) on hot summer day (mean ± SD).**

| Time of Day | Body Temperature, °C (°F) | | Outside $T_a$, °C (°F) | Inside $T_a$, °C (°F) | Inside RH, (%) |
|---|---|---|---|---|---|
| | TV | TV + DC | | | |
| 0730 h | 38.1 ± 0.4 (100.6 ± 0.7) | 39.0 ± 0.30 (102.2 ± 0.5) | 26.8 (80.2) | 27.5 ± 0.5 (81.5 ± 0.9) | 89 ± 1 |
| 1030 h | 39.3 ± 0.4 (102.7 ± 0.7) | 38.9 ± 0.1 (102.0 ± 0.2) | 28.8 (83.8) | 29.3 ± 0.4 (84.7 ± 0.7) | 90 ± 3 |
| 1200 h | 39.5 ± 0.3 (103.1 ± 0.5) | 38.8 ± 0.2 (101.8 ± 0.4) | 29.2 (84.6) | 29.5 ± 0.3 (85.1 ± 0.5) | 90 ± 3 |
| 1400 h | 39.6 ± 0.3 (103.3 ± 0.5) | 39.2 ± 0.7 (102.6 ± 1.0) | 29.5 (85.1) | 29.3 ± 0.5 (84.7 ± 0.9) | 90 ± 2 |
| 1600 h | 39.2 ± 0.3 (102.6 ± 0.5) | 39.1 ± 0.4 (102.4 ± 0.7) | 31.2 (88.2) | 30.4 ± 0.3 (86.7 ± 0.5) | 86 ± 4 |

## References


ASHRAE. 1997. *ASHRAE Handbook — Fundamentals*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air–Conditioning Engineers, Inc.

Harmon J. D., and H. Xin. 1996. *Thermal Environment Guidelines for Swine Housing.* Livestock Industry Facilities Environment Series, Ames, Iowa: Iowa State Univ.

Lu, Y. 1987. *Heating and Ventilation Handbook* (in Chinese), 773–901. Beijing, China: Beijing Building Publishing House.

MWPS, 1990. *Structures and Environment Handbook.* Ames, Iowa: Iowa State University.

Riskowski, G. L., and D. S. Bundy. 1991. Response of young pigs to various air temperature and velocities. *ASHRAE Trans.* 97(2): 543–549.

Xin, H., and J. A. Deshazer. 1991. Swine responses to constant and modified diurnal cyclic temperatures. *Trans. ASAE* 34(6): 2533–2540.